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Plastic Ingestion and PCBs in Seabirds: Is There a Relationship?

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Multivariate analyses were used to assess the independent determinants of four organochlorines (OCs) in the fat and eggs of breeding female Great Shearwaters *Puffinus gravis*. The amounts of polychlorinated biphenyls (PCBs), DDE, DDT, and dieldrin, in both adult fat tissue and in eggs were positively correlated. However, there was no correlation between the amounts of OCs in adults and their eggs. Positive correlations between the amounts of different OCs in adults and in eggs suggest that individual differences in non-breeding range, diet and age are determinants of pollutant levels within a species. The mass of ingested plastic was positively correlated only with PCBs, a group of chemicals commonly found in plastics. It is probable that seabirds assimilate PCBs and other toxic chemicals partly from ingested plastic particles.

Polychlorinated biphenyls (PCBs) have become ubiquitous pollutants of marine food webs over the last 20 yr, and are particularly prevalent in seabirds (see Bourne, 1976; Ohlendorf *et al.*, 1978 for reviews). Although adverse effects from PCBs are not always apparent (Harris & Osborn, 1981), PCBs may have deleterious effects on birds, including reduced breeding success, increased risk of disease, and altered hormone levels, as well as direct mortality (e.,g. Friend & Trainer, 1970; Peakall & Peakall, 1973; Peakall, 1975; Bourne, 1976; Jefferies & Parslow, 1976; Gilbertson & Fox, 1977; Ohlendorf *et al.*, 1978; Tori & Peterle, 1983).

It is generally assumed that PCBs enter birds via their prey, the high levels in seabirds resulting from progressive accumulation between trophic levels (e.g. Bourne, 1976; Ohlendorf *et al.*, 1978; Newton, 1979). However, PCBs are used in the manufacture of many types of plastics (Gregory, 1978), and they are adsorbed to plastic particles at sea (Carpenter *et al.*, 1972), so that plastic ingested by seabirds and retained in the stomach for some time might be a direct source of PCBs (and other toxic chemicals) to seabirds (Day, 1980; Pettit *et al.*, 1981; Bourne & Imber, 1982; van Franeker, 1985). There is no published evidence to support this hypothesis, and experiments to determine the importance of ingested plastics as sources of toxic chemicals to seabirds are considered a priority (van Franeker, 1985).

This study compares the amount of PCBs in the fat and eggs of Great Shearwaters *Puffinus gravis* with their plastic loads and with levels of other organochlorine (OC) pollutants. Great Shearwaters are particularly suitable study animals, because they contain very high levels of ingested plastic, a large proportion of which is manufactured (user) plastic (Ryan, 1988), the type with the highest levels of PCBs and other toxic chemical additives (Gregory, 1978; van Franeker, 1985).

Materials and Methods

Twenty female Great Shearwaters and their eggs were collected within two days of laying eggs at Gough Island (40° 21′S, 9° 53′W), South Atlantic Ocean, between 9 and 12 November 1984. Eggs were wrapped in aluminium foil and refrigerated for later analysis. Fat samples collected from abdominal fat deposits were wrapped in aluminium foil and frozen. The mass of the bird less stomach contents, egg mass (both to the nearest 1 g), and the mass of abdominal fat reserves (to the nearest 0.1 g) were recorded within 2 h of collection. Plastic loads were determined by dissecting out the stomach (proventriculus and gizzard) and collecting all plastic particles. The particles were washed, oven dried at 30°C, and then weighed to the nearest 0.1 mg. Plastic load was taken to be the total mass of plastic in each bird at the time of collection.

The OC pollutants, PCB (as Aroclor 1260), pp′DDE, pp′DDT, and dieldrin, were extracted from fat and egg samples, passed through a cleanup column, and their concentrations measured using gas chromatography (see Gardner *et al.*, 1985 for further details). Two adult fat samples were contaminated and were not included in the analyses. Due to the variability in the mass of adult fat reserves, an index of OC body load was used in preference to measures of concentration (cf. Ohlendorf *et al.*, 1978), derived by multiplying the concentration of pollutant by the mass of abdominal fat reserves. Abdominal fat mass was assumed to be indicative of total fat reserves (e.g. Thomas & Mainguy, 1983), which is supported by the strong correlation between the mass of abdominal fat reserves and bird mass (Ryan, 1987). The small variation in egg mass did not warrant correction for OC loads.

Stepwise multiple correlation analyses were performed using Statpro (Imhoff & Hewett, 1983) to assess the independent influences of bird mass, egg mass, the mass of abdominal fat reserves, plastic loads and other OC loads on the PCB load of female Great Shearwaters and the concentration of PCBs in their eggs. Multivariate analyses were also used to determine the parameters independently influencing each of the other OCs measured, and to assess the effect of large correlations between pollutants. Analyses were terminated when no additional variable was correlated at below the 0.05 significance level.

Results

Plastic was present in 19 (95%) female Great Shearwaters sampled, and there was large variation in plastic loads and OC concentrations in fat tissue and eggs (Table 1). The concentration of dieldrin in eggs was too low for accurate determination. A negative correlation between PCB concentration in adult fat tissue and the mass of abdominal fat ($r=-0.439$, d.f.$=16$, one-tailed $P<0.05$) necessitated the calculation of adult OC load indices.

There were no significant correlations between the OC loads or concentrations in adult fat tissue and OC concentrations in eggs. However, several OC loads in adult fat tissue were positively correlated, as were all OC concentations in eggs (Table 2). Two pairs of OC concentrations in adult fat tissue also were positively correlated, but to a lesser degree than the correlations of pollutant loads. This suggests that the observed correlations between different OCs are not an artefact of variable masses of fat reserves.

The high degree of correlation between different OC loads in adult fat tissue dominated the results from the multivariate analyses. The magnitudes of all OC loads were most highly correlated with other OC loads (Table 3). The mass of ingested plastic was not significantly correlated with any variable, being best correlated with adult PCB load ($r=0.33$). However, residual variation in adult PCB load was significantly correlated (positively) with plastic, and the residual variation in adult DDE load was negatively correlated with plastic (Table 3).

OC concentrations in eggs also were most highly correlated with the concentrations of other OCs (Table 3). The mass of abdominal fat was negatively correlated with the concentrations of DDE and DDT in eggs.

Discussion

Mean concentations of PCBs and DDE in Great Shearwater eggs sampled in 1984 were almost twice those recorded from eggs collected at the same locality in 1979 (n$=3$, Gardner *et al.,* 1985), although neither difference was significant due to the small sample sizes. No apparent change in the mean DDT concentrations occurred between 1979 and 1984.

TABLE 1

Mean values, standard deviations and ranges of pollutant loads in breeding female Great Shearwaters and their eggs.

Parameter	Mean	S.D.	Range	n
Plastic mass (mg)	295.0	381.9	0.0–1441.0	20
Adult concentrations (μg.kg^{-1} fat)				
PCBs	2407	1305	800–5895	18
DDE	659	405	0–1425	18
DDT	207	200	0–740	18
Dieldrin	76	62	0–223	18
Egg concentrations (μg.kg^{-1} whole egg)				
PCBs	535	618	93–2549	20
DDE	119	104	20–471	20
DDT	5	6	0–20	20

TABLE 2

Simple linear correlation coefficients (r) between OC loads in Great Shearwater adults (A) and concentrations in their eggs (B). Significance level is given by the number of symbols (+), 1$=P<0.05$, 3$=P<0.001$.

A—Adult loads	PCBs	DDE	DDT	Dieldrin
PCBs	1.000	0.769	0.286	0.229
DDE	+++	1.000	0.497	0.297
DDT		+	1.000	0.503
Dieldrin			+	1.000

B—Egg concentrations	PCBs	DDE	DDT
PCBs	1.000	0.731	0.842
DDE	+++	1.000	0.727
DDT	+++	+++	1.000

TABLE 3

The independent parameters associated with OC loads and concentrations in female Great Shearwater fat reserves and in their eggs.

Dependent variable	Independent variable	Sign	Cumulative r^2
Adult PCB load	Adult DDE load	+	0.591
	Plastic load	+	0.700
Adult DDE load	Adult PCB load	+	0.591
	Adult DDT load	+	0.674
	Plastic load	−	0.740
Adult DDT load	Adult dieldrin load	+	0.253
	Adult DDE load	+	0.385
Adult dieldrin load	Adult DDT load	+	0.253
Egg PCB concentration	Egg DDT concentration	+	0.708
	Egg DDE concentration	+	0.764
Egg DDE concentration	Egg PCB concentration	+	0.535
	Abdominal fat mass	−	0.665
Egg DDT concentration	Egg PCB concentration	+	0.708
	Abdominal fat mass	−	0.810

The lack of significant positive correlations between OC concentrations in eggs and those stored in adult fat tissue is not unexpected, because a variable proportion of stored OCs are removed from the body during egg laying (Vermeer & Reynolds, 1970; Dahlgren *et al.,* 1971; Subramanian *et al.,* 1986). OCs found in eggs are derived from both direct intake in food during egg-formation and from body stores (Newton, 1979; Harris, 1984). The negative correlation between abdominal fat mass and the concentrations of DDE and DDT in Great Shearwater eggs presumably resulted from greater concentration of OCs in the fat of birds with small fat reserves. The use of the same amount of stored energy reserves (fat) during egg formation would be accompanied by the release of greater amounts of OCs in birds with small fat reserves than in those with large reserves (Bogan & Newton, 1977; Subramanian *et al.*, 1986).

Positive correlations between the loads of different OCs in bird tissues have been widely recorded (e.g. Newton & Bogan, 1974; Blus, 1982; Norheim & Kjos-Hanssen, 1984). Such correlations suggest that differences between individuals are important in determining the magnitude of OC loads in seabirds. Differences in non-breeding range, diet and bird age could result in constant inter-individual differences in a broad suite of pollutants in seabirds, assuming that pollutants are concentrated around source areas (for non-breeding range—e.g. Norheim & Kjos-Hanssen, 1984), vary between prey types (for diet), or are accumulated with age (e.g. Subramanian *et al.*, 1986).

The positive correlation between PCBs and plastic loads in Great Shearwaters may also result from differences between individuals; 'dirty' birds, characterized by high levels of both OCs and ingested plastic, differing from 'clean' birds as a result of different lifestyles (non-breeding areas and/or diet). Age differences presumably would not result in correlations between plastic and OCs in Great Shearwaters, because plastic is not accumulated with age, and is highest in immature birds (Ryan, in press).

If the correlation between PCBs and plastic loads was an effect of differences between the lifestyles of individuals, plastic should be positively correlated with the other OCs, DDE, DDT and dieldrin. No such correlations were detected, therefore it is likely that PCBs were derived from ingested plastic particles and that these contribute significantly to the total body load of PCBs in Great Shearwaters.

The PCB loads recorded from Great Shearwaters are not high compared to those of certain seabirds in the northern hemisphere (Ohlendorf *et al.*, 1978). Ingested plastic is unlikely to be a major contributor to the PCB loads of birds with high OC loads, because the concentration of PCBs in most plastic particles is low (Gregory, 1978). However, plastics contain many other additives, some of which are toxic (van Franeker, 1985), and whose synergistic effects with other pollutants are unknown. This study presents the first evidence to suggest that seabirds assimilate chemicals from the plastic particles in their stomachs. Confirmation of this pathway for potentially dangerous pollutants could be achieved by identifying specific plastic-associated chemicals within seabird tissues.

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